Measurement of the radiation field surrounding the Collider Detector at Fermilab

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Motivation / Outline

What

First extensive measurement of the radiation field surrounding a hadron collider, specifically, the Collider Detector at Fermilab.

Why

Radiation environment surrounding the detector $\Rightarrow$ constraints on reliability and lifetime of the detector and its infrastructure.

How

Use Thermal Luminescent Dosimeters (TLDs), placed around the detector

Results

Dosimeters exposed during two different phases of the CDF operation: evaluate effectiveness of installed shielding and construct a map of the ionizing radiation field

Experimental environment: the collider

Tevatron:

• Proton-antiproton collider, at Batavia, IL, of 1 km radius

• Circulating protons and antiprotons collide every $\sim$ 396 ns at two designated points around the Tevatron

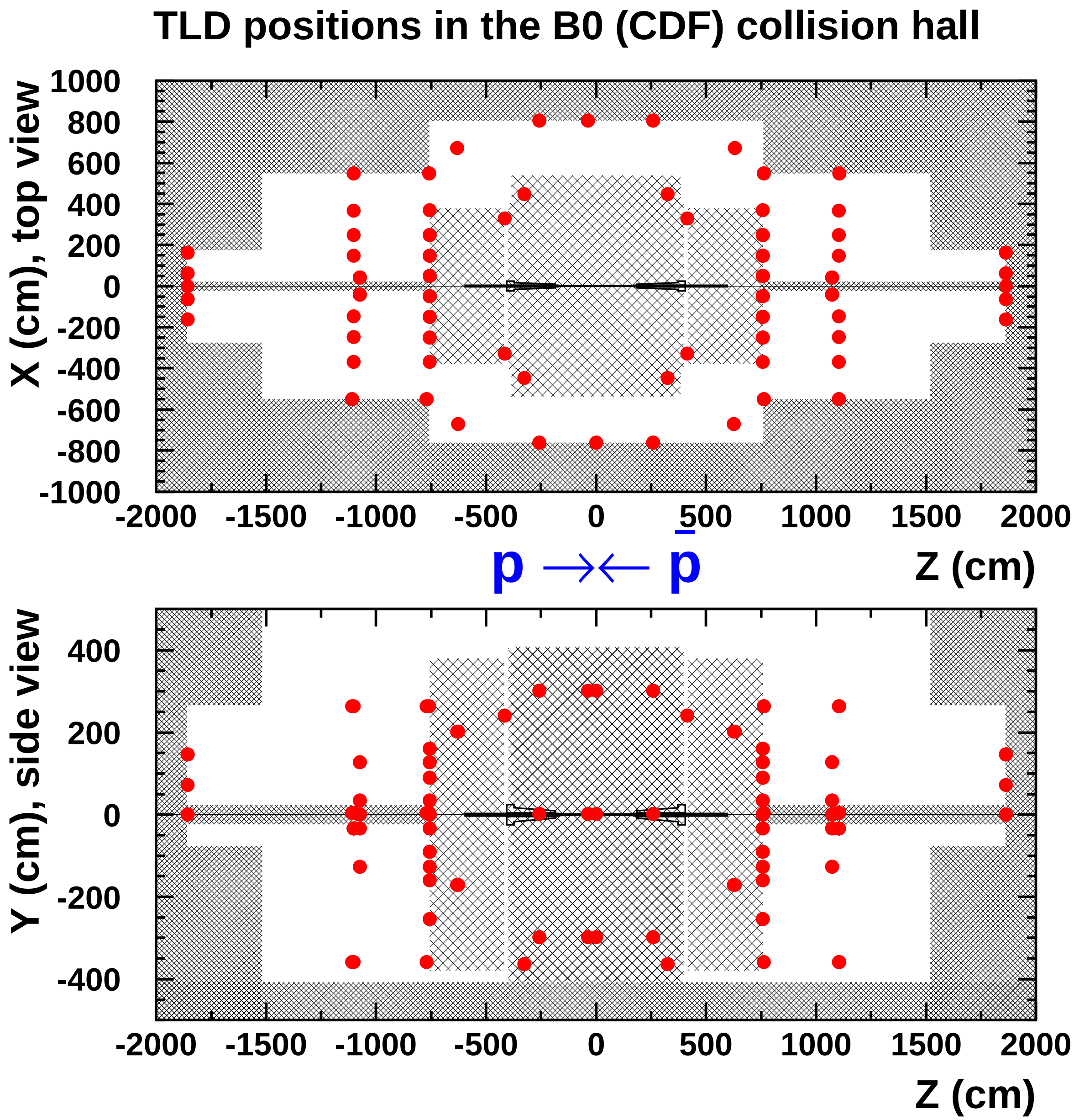
• Collision energy = 2 TeV ($\simeq$ 2000 times the proton mass).

Experimental environment: the detector

- Collider Detector at Fermilab (CDF) surrounds one of the Tevatron collision points and measures produced particles

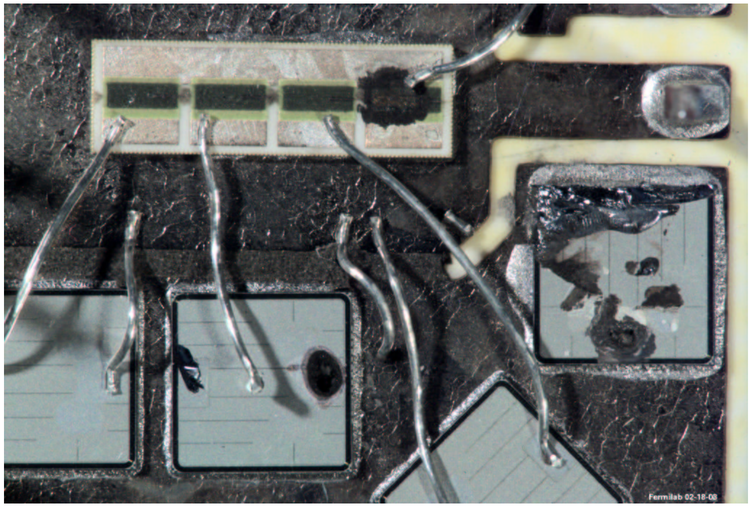
- Collision hall not empty. Hosts readout electronics and power supplies for detector components.

- Each collision produces $\sim$ 32 primary charged particles traversing the volume covered by the TLD locations.



Experimental environment: radiation

Radiation poses operational problems: steady-state, disruptive (single-event upsets), or even catastrophic (single-event burnouts, etc.)



Measure radiation field: Thermal Luminescent Dosimeters

Advantages:

+ Industry standard
+ Continuously integrate radiation
+ Passive devices:
  no active readout, no power
+ Large dynamic range:
  1 mRad to 200 kRad
+ Very good precision
+ On site TLD reader → fast turn around

Disadvantages:

– Require harvesting individual dosimeters

– Large amount of handling

Radiation measurement: How?

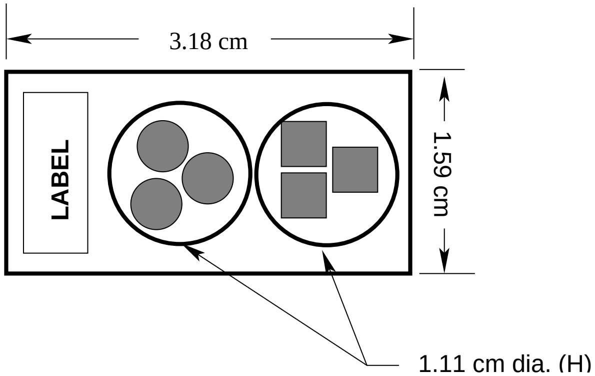
Two types of Thermal Luminescent Dosimeters:

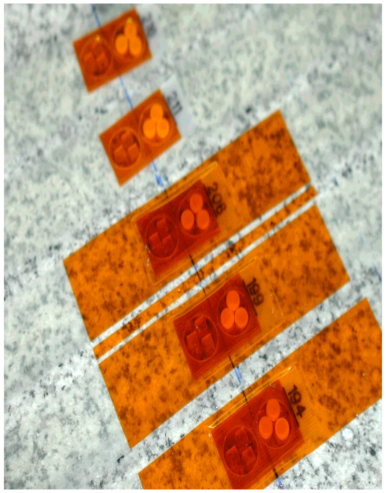
- TLD-700 (^{7}LiF): sensitive to ionizing radiation
- TLD-600 (^{6}LiF): sensitive to both ionizing radiation and low energy neutrons ($E < 200$ keV)

TLD calibration:

- Ionizing radiation: 1 Rad exposure to a ^{137}Cs source
  $\sim 1\%$ reproducibility and $\sim 3\%$ chip-to-chip variation
- Neutron calibration: 10 mRad exposure to ^{252}Cf source
  $\sim 10\%$ reproducibility and $\sim 15\%$ chip-to-chip variation.

$\sim$ 1000 TLDs around the collision hall, in triplets for redundancy (160 holders)





Radiation measurement: TLD exposure

Three TLD exposure periods analyzed:

1) May - Jun 2002: no shielding, partial TLD installation

2) Jun - Oct 2002: no shielding, complete set of TLDs

3) Jan - May 2003: shielding on the incoming proton side

	Beam ($\times 10^{18}$)		Losses ($\times 10^{9}$)		$\int L dt$
Period	p	$\bar{p}$	p	$\bar{p}$	(pb^{-1})
1) May-Jun'02	4.34	0.19	8.16	1.41	5.49
2) Jun-Oct'02	31.7	1.92	80.1	11.3	56.4
3) Jan-May'03	29.4	2.32	61.5	7.5	74.8

(**Note:** 1 pb^{-1} corresponds to $\sim 5 \times 10^{10}$ $p\bar{p}$ interactions)

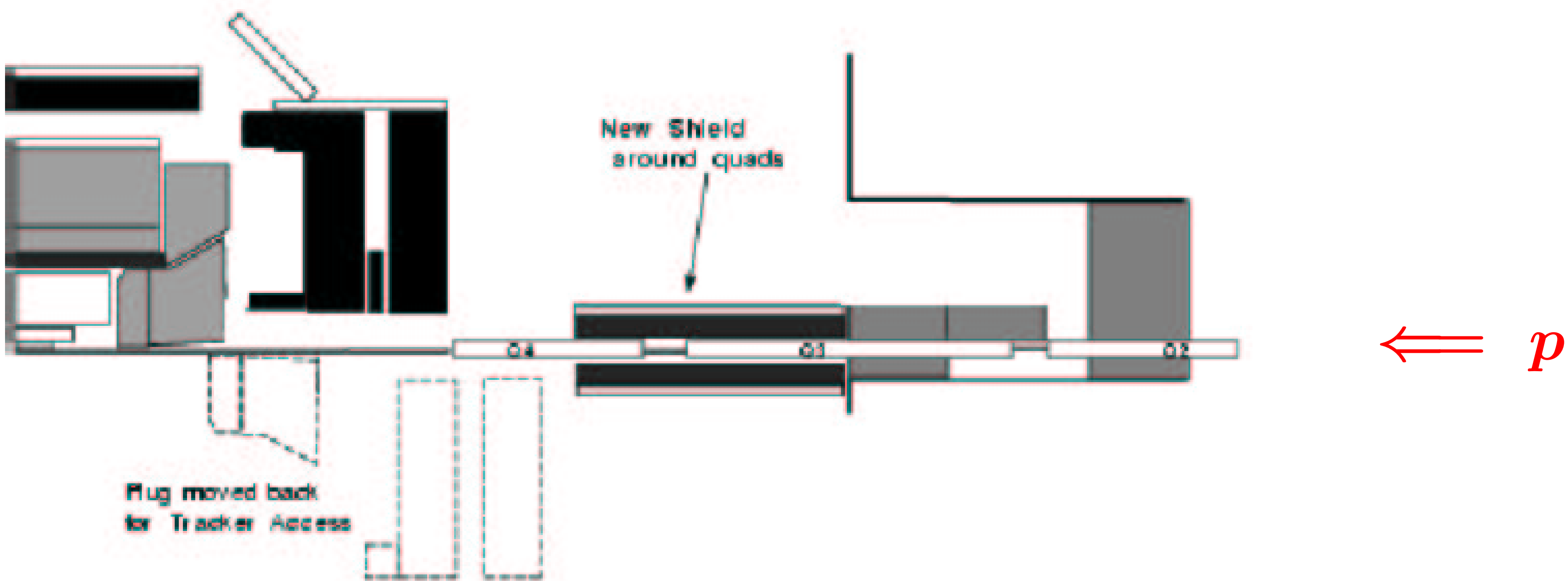
- Number of collisions (luminosity at CDF location): measured by Cherenkov radiation counters.

- Losses of incoming proton (p) and antiproton ($\bar{p}$) beams: monitored by scintillator counters and by ionization chambers, on each side of CDF close to the beam pipe.

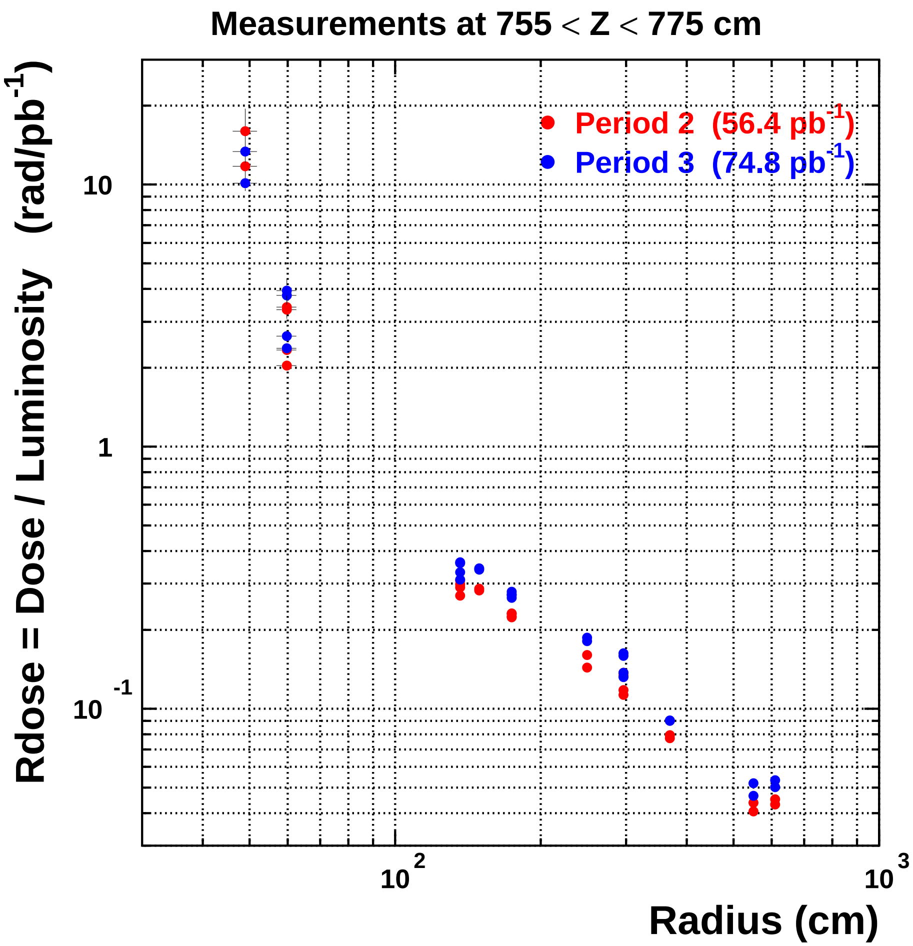
The shielding: Period 3

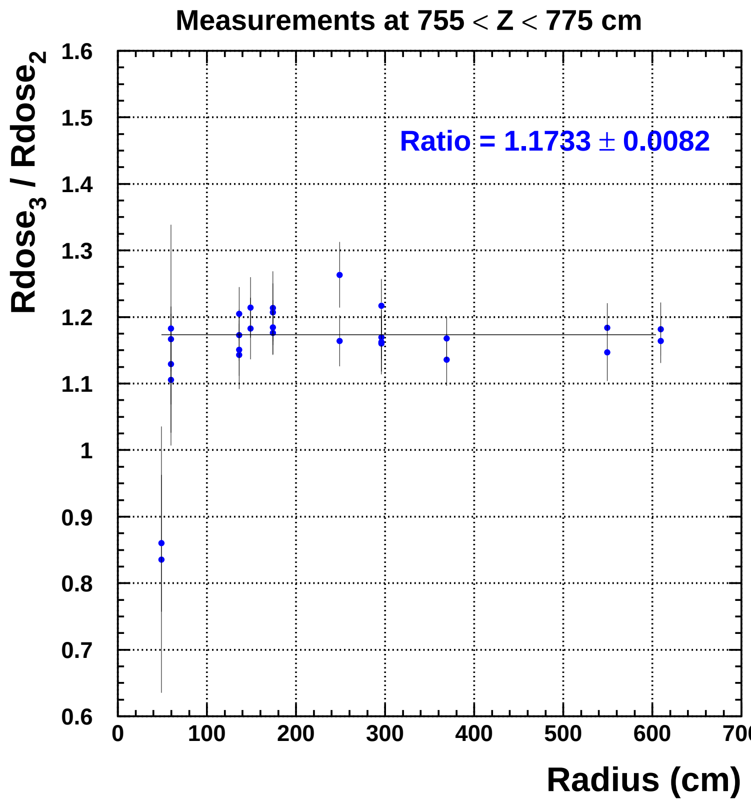
The detector and its infrastructure are exposed to radiation from
a) products of $p\bar{p}$ collisions, and
b) losses from the beams as they come to/leave the collision point

Shielding was installed in Jan. 2003 to reduce the beam loss contribution on the proton (p) side:



Measurements at $Z \simeq 765$cm, $\bar{p}$ side





Simple scale, tells many things:

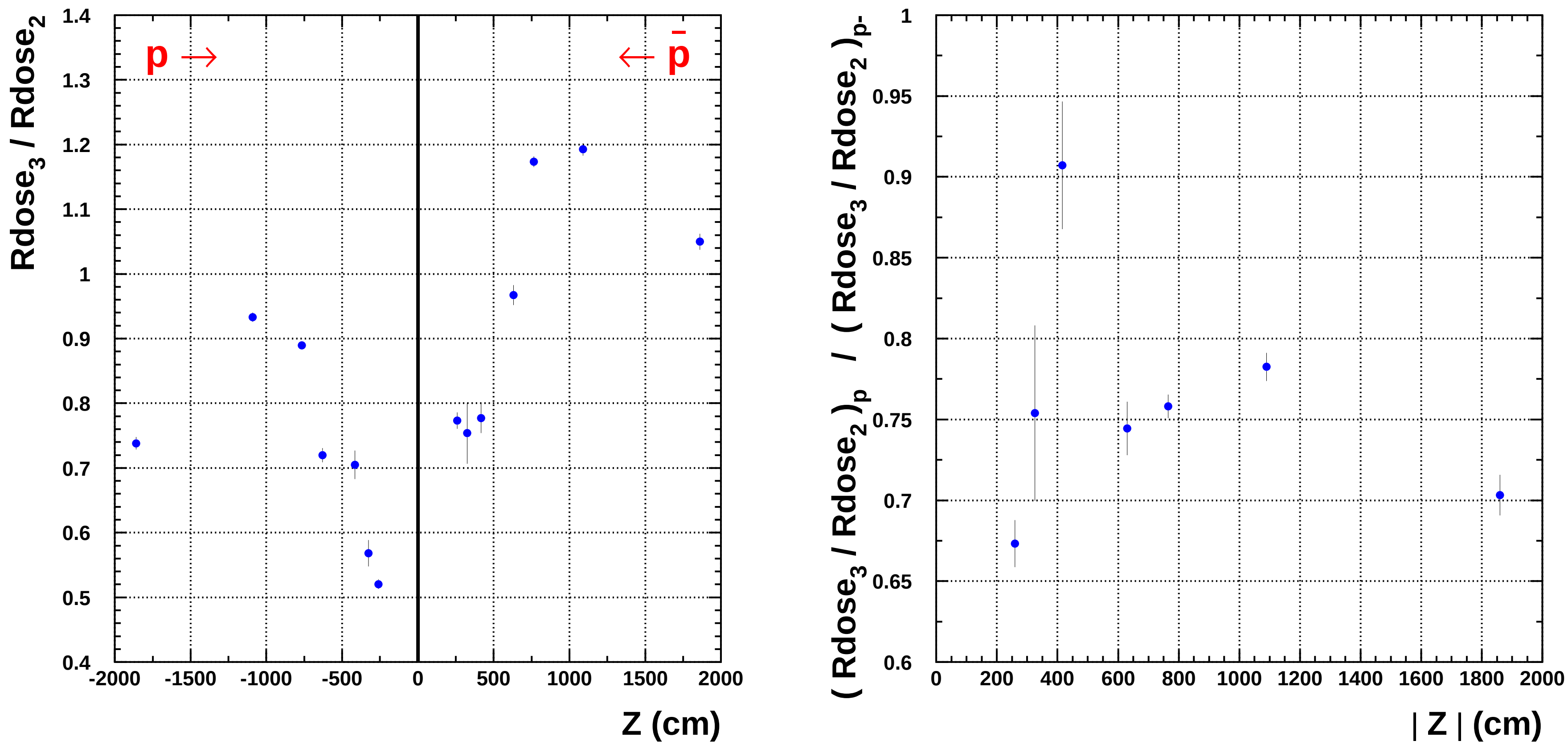
$$Dose = Dose_C + Dose_L \Rightarrow Rdose \equiv \frac{Dose}{Lum} = \frac{Dose_C}{Lum} + \frac{Dose_L}{Lum}$$

a) Ratio $\neq 1 \Rightarrow$ losses contribute to dose

b) Ratio $> 1 \Rightarrow Dose_L/Lum$ in period 3 is higher than in period 2

Dose rates in Period 3 relative to Period 2

Rdose = Dose / Luminosity



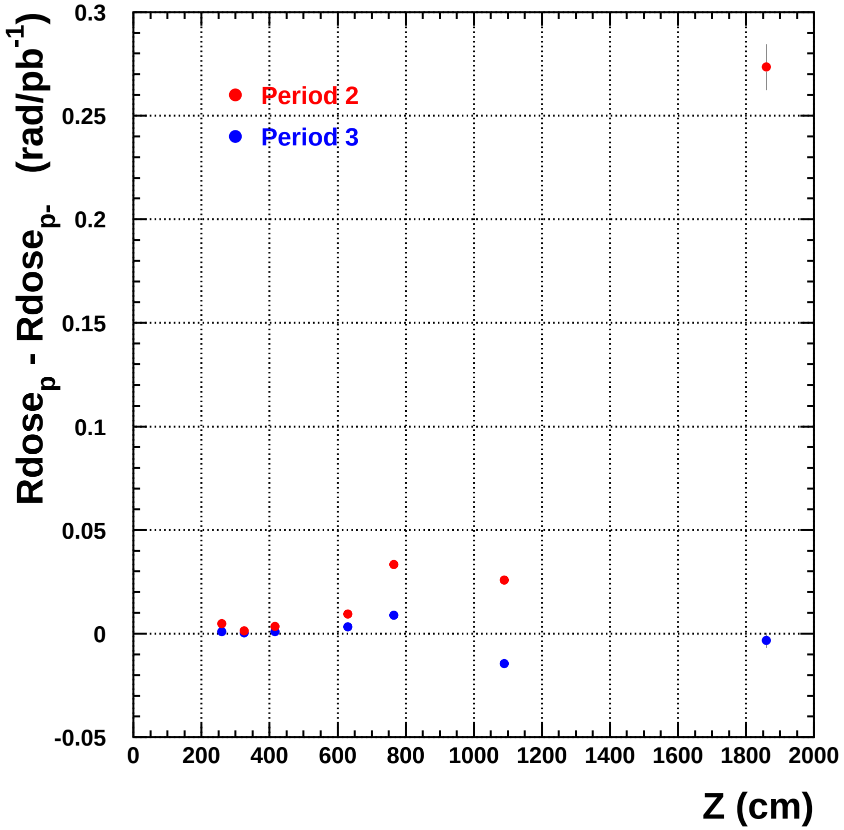
On the proton side, dose rates went down in period 3 ("shielding period") by $\sim$ 25%

Compared to the $\bar{p}$ side, dose rates on p side are at typically 25% lower in period 3.

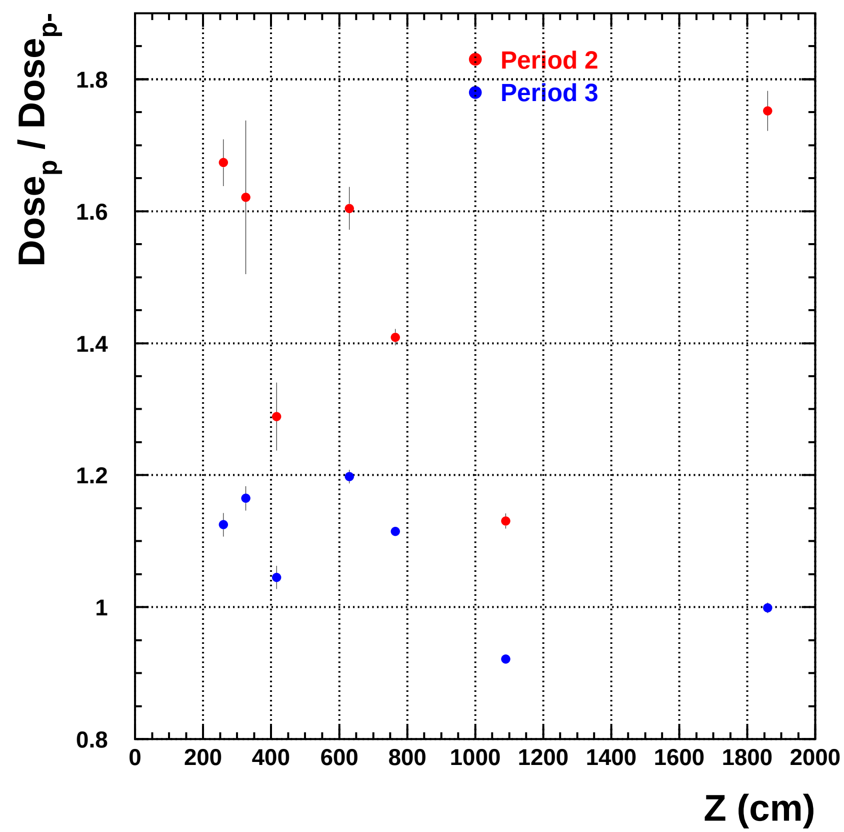
Dose rates on p side vs. $\bar{p}$ side

$$Dose = Dose_C + Dose_L \Rightarrow D = D_C + D_L$$

$$D_p - D_{\bar{p}} = \Delta D_L$$



$$\frac{D_p}{D_{\bar{p}}} = \frac{D_{C,p}+D_{L,p}}{D_{C,\bar{p}}+D_{L,\bar{p}}}$$



With shielding, dose due to losses is more similar on both sides.

Dose rates on p side within 20% or $\bar{p}$ side now.

Modeling the ionizing radiation field

a) Losses are not negligible, even in the $\bar{p}$ side

b) Shielding on the p side has reduced dose rates by $\sim 25\%$

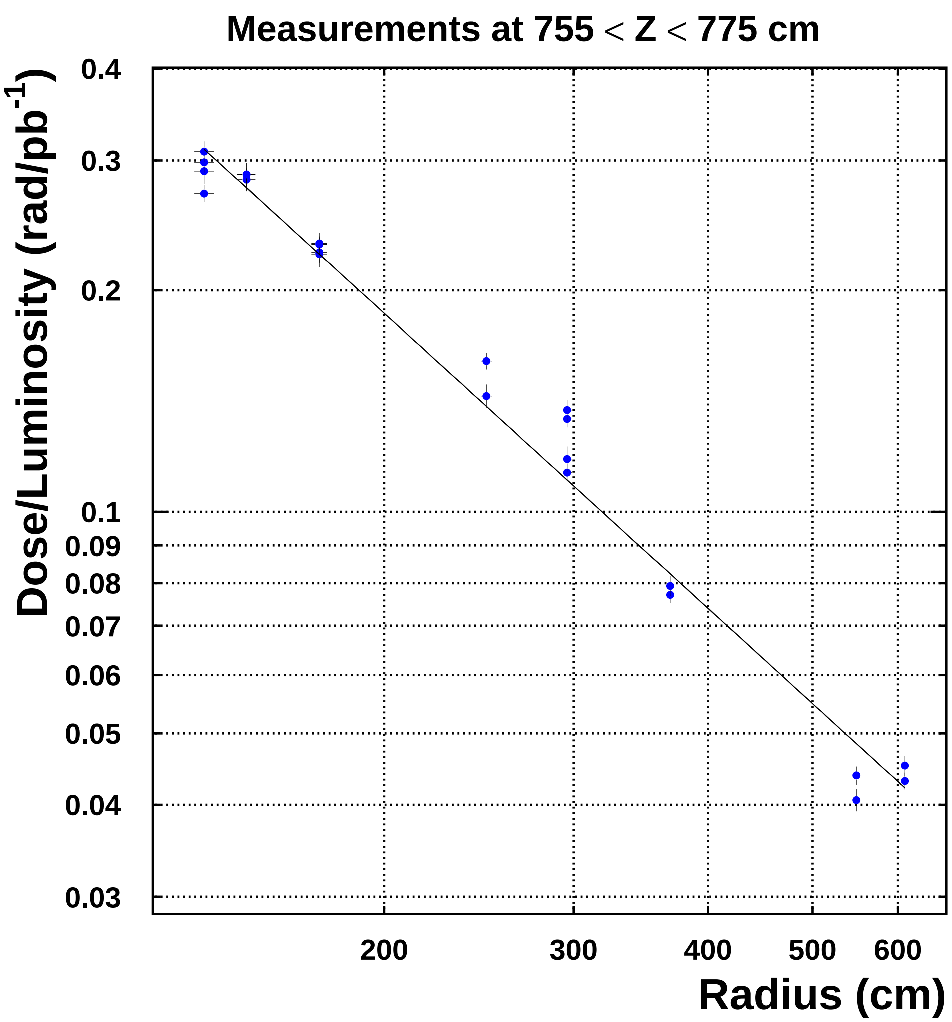
c) No separation of loss/collision contribution point-by-point

$\Rightarrow$ construct total radiation field.

Simple model (D. Amidei et al.: NIM **A320** (1994) 73)

- Cylindrical symmetry about the beam
- Field follows power law in $1/r$ (r = distance from beam)

$$\boxed{\text{Dose}(r) = A r^{-\alpha}}$$

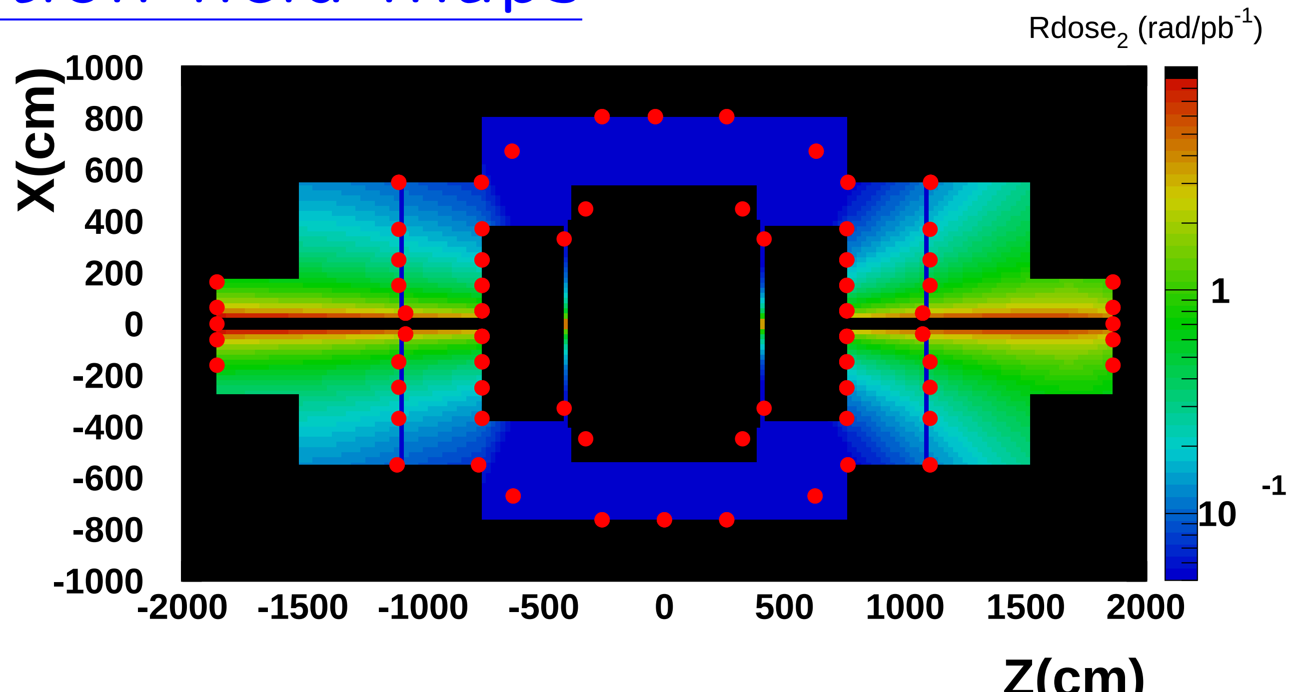


Ionizing radiation field maps

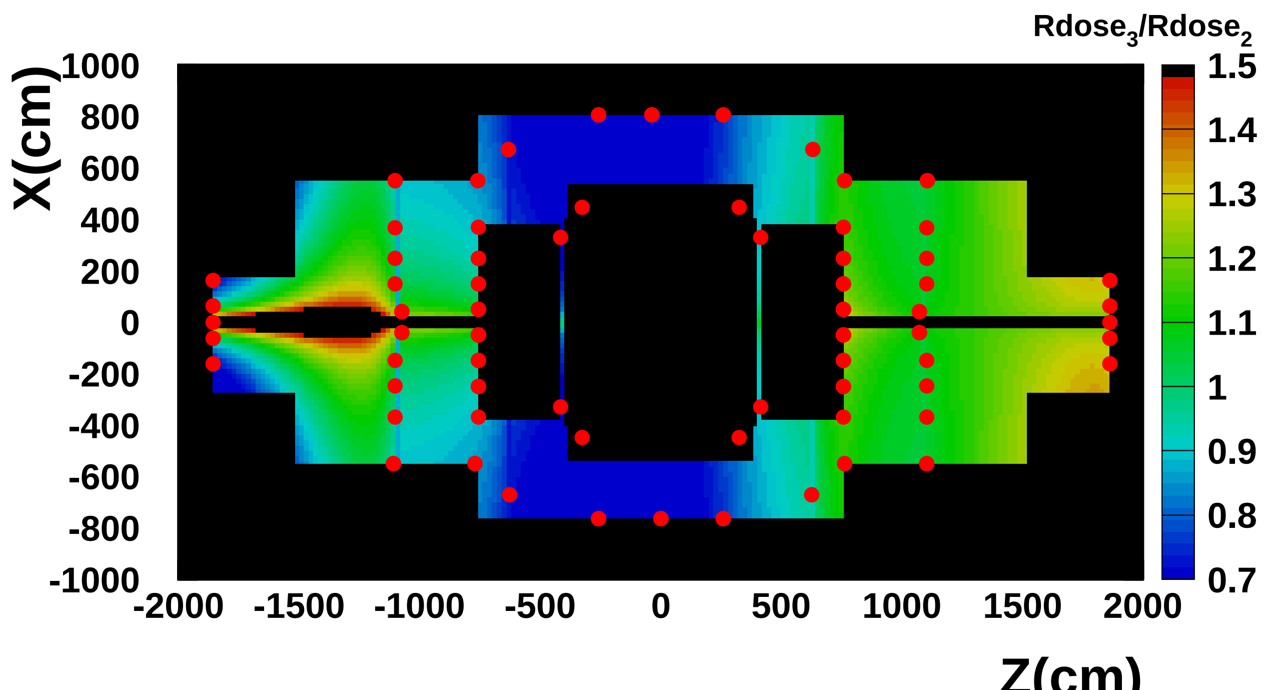
Linear interpolation between measurements

⇒ radiation field map

Period 2, no shielding on p side yet:



Changes in Period 3, with shielding on p side:



Summary

- Installed $\sim$ 1000 TLDs in the collision hall of the Collider Detector at Fermilab:
  measured ionizing and low energy neutron ($E_n < 200$ keV) radiation

- TLDs provide accurate measurement of the radiation field:
  Ionizing radiation $\sim 5\%$ uncertainty

- Observed a $\sim 25\%$ reduction on the dose rate on the side where the shileding was installed.

- Build a simple model for the ionizing radiation field

PS: Thanks to Minjeong Kim and Fabio Happacher for helping in placing/harvesting the dosimeters, to the Fermilab Si lab people for the packaging, and the radiation monitoring people at Argonne labs for letting us use their TLD reader when needed.

Appendix1: Dosimetry

Ionizing radiation dosimetry:

$$D_\gamma = C \cdot k_\gamma R_{700} - D_{\gamma,control} \quad (1)$$

R_{700}	TLD-700 reading (nC)
k_γ	ionizing radiation calibration constant (Rad/nC)
C	non-linearity correction
$D_{\gamma,control}$	control dosimeters' ionizing dose (background level)

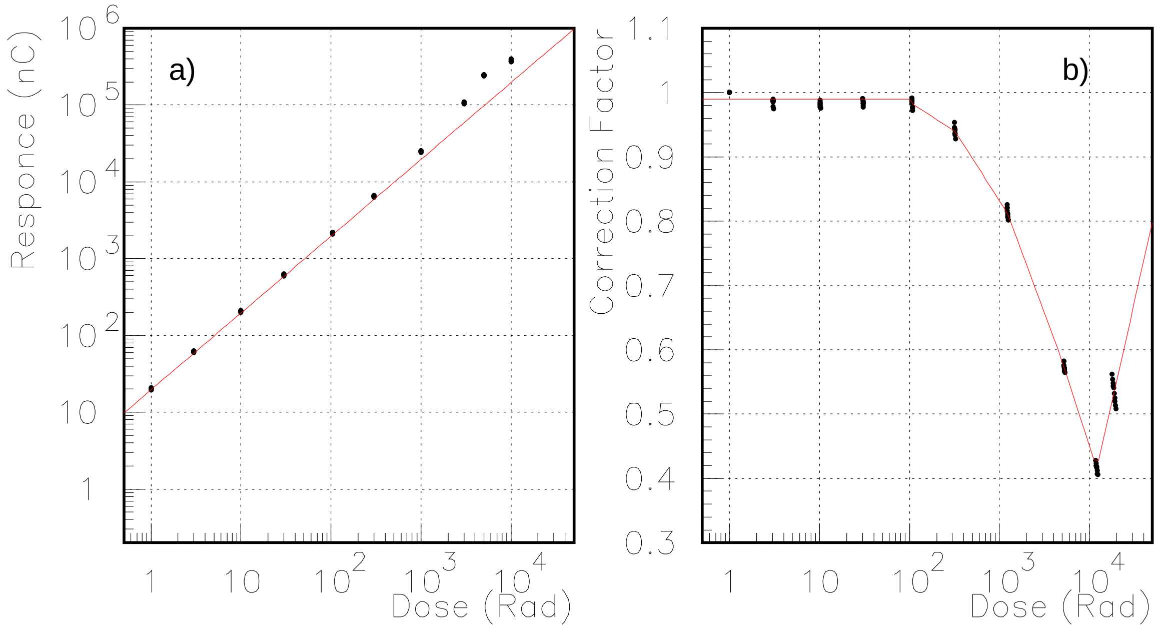
Neutron radiation dosimetry:

$$D_n = \frac{k_n}{k_\gamma}(C \cdot k_\gamma R_{600} - D_\gamma) - D_{n,control} \quad (2)$$

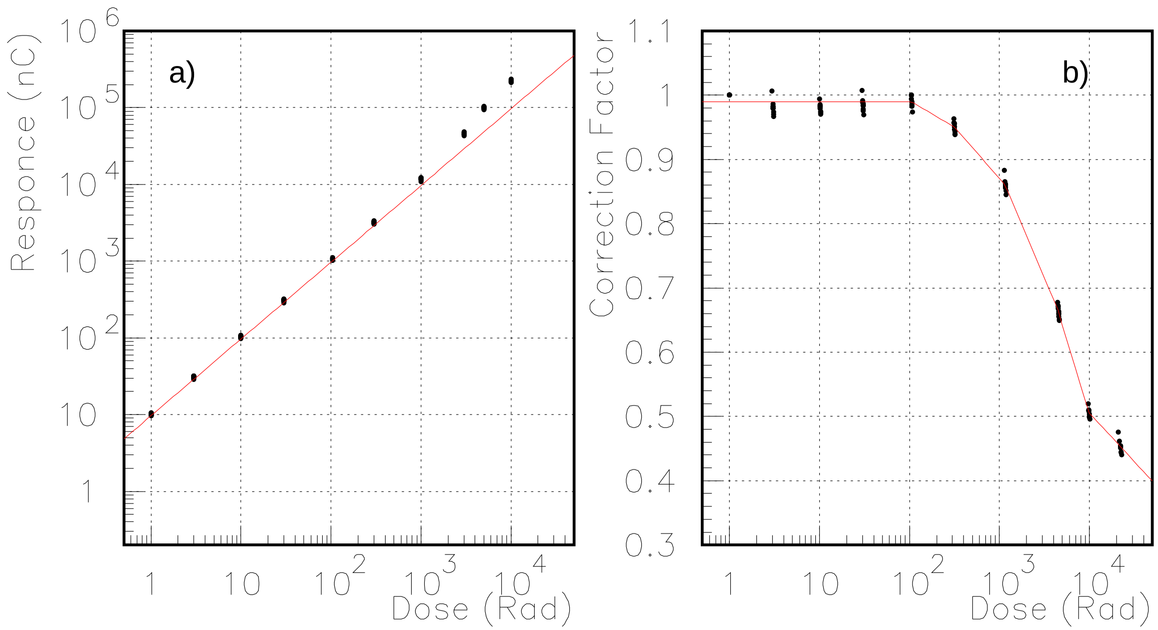
R_{600}	TLD-600 reading (nC)
k_γ	Ionizing radiation calibration constant (Rad/nC)
k_n	Neutron radiation calibration constant (Rad/nC)
C	non-linearity correction
D_γ	ionizing radiation dose, from the TLD-700's at the same spot
$D_{n,control}$	control dosimeters' neutron dose (background level)

Appendix2: TLD response, linearity

TLD-700 response to ionizing radiation (^{137}Cs)

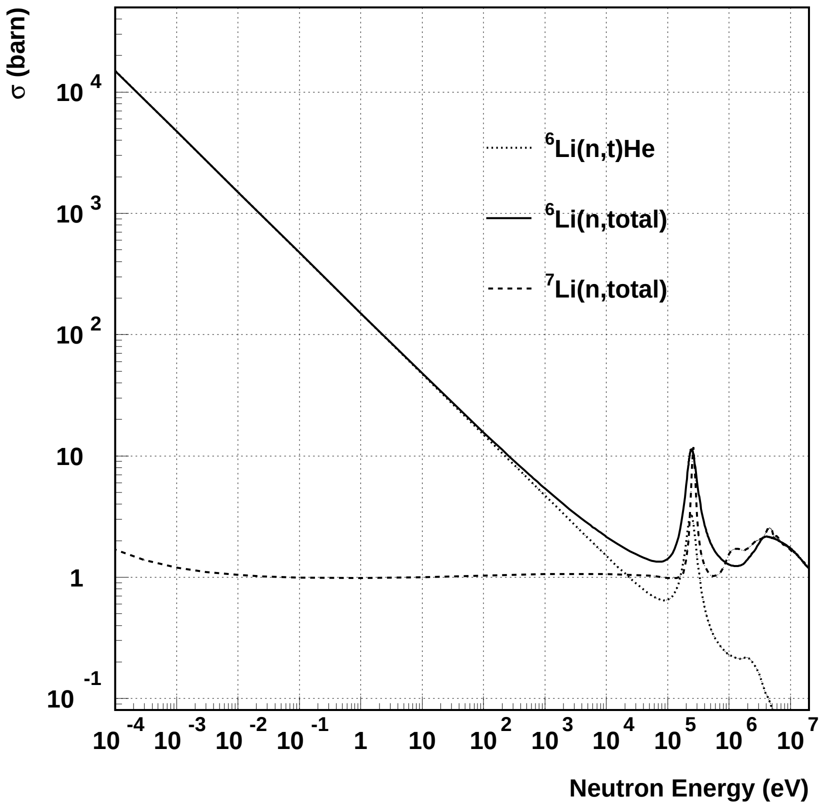


TLD-600 response to ionizing radiation (^{137}Cs)



Appendix3: ^{6}Li neutron absorption

Neutron absorption cross section of ^{6}Li and ^{7}Li



Neutron emission spectrum of ^{252}Cf